

Probing the Proton Spin Structure with W bosons at PHENIX

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The recent and continuing collisions at RHIC of polarized protons at $\sqrt{s}=500$ GeV will provide access to new and exciting probes of the proton spin structure. The production of W bosons will allow clean flavour separation of the quark sea providing independent measurements of longitudinal \bar{u} and \bar{d} polarization via parity-violating single-spin asymmetries. PHENIX has the ability to measure W boson decays to electrons at mid-rapidity ($|\eta| < 0.35$) and, with several upgrades, decays to high p_T single muons at forward rapidity ($1.2 < |\eta| < 2.4$). These features place PHENIX in a unique position to explore W boson production in polarized proton collisions.

1 Anti-quark Polarization in the Proton

A great deal of progress has been made in measuring longitudinally polarized parton distributions in the proton. However, even the most recent NLO QCD global analysis [2] using, for the first time, proton-proton data from RHIC along with DIS and SIDIS data, is not able to adequately describe the longitudinal polarization of anti-quarks in the proton. Current constraints on the anti-quarks come mostly from SIDIS. Unlike DIS, SIDIS measures both the scattered lepton from an electron-proton collision and an outgoing hadron, which is used to tag the flavour of the scattered quark.

Unfortunately, flavour tagging methods in SIDIS rely a great deal on theoretical unfolding using fragmentation functions. A much cleaner measurement of the longitudinally polarized anti-quark distributions can be made using W bosons produced in proton-proton collisions. Since W boson production is purely V-A the helicity of the incoming quarks is fixed so that the unfolding of the longitudinal polarizations of the anti-quarks is straightforward and would provide a very complimentary measurement to those obtained with SIDIS. A minor disadvantage to W boson measurements at PHENIX is that the W boson cannot be measured directly but only through its decay to leptons, an effect which dilutes the measured asymmetries.

In polarized proton-proton collisions the longitudinally polarized \bar{u} and \bar{d} are accessed through a measured single spin asymmetry of the produced leptons

$$A_L = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$$

where $\sigma_{+(-)}$ is the cross section for a W boson decay from the scattering of a longitudinally polarized proton with positive(negative) helicity on an unpolarized proton. If the W boson

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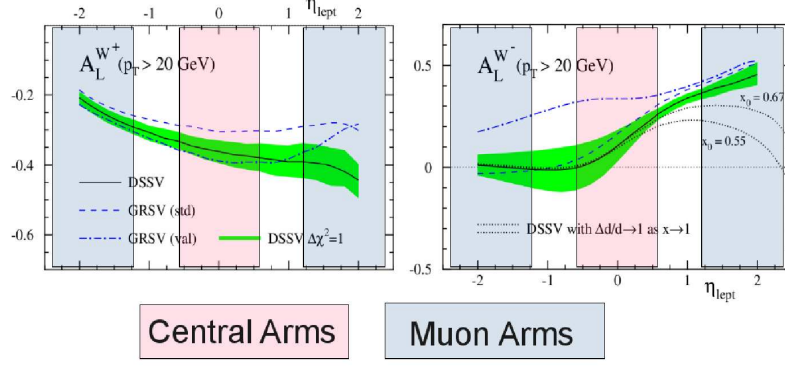


Figure 1: Single Spin Asymmetries for leptons from W decays in the PHENIX central ($|\eta| < 0.35$) and forward ($1.2 < |\eta| < 2.2$) acceptance. Uncertainty bands are for $\Delta\chi^2 = 1$ from the most recent global NLO QCD fit. (Plot from [2])

were measured directly such an asymmetry could be written as

$$A_L^{W^+} = \frac{\Delta\bar{d}(x_1)u(x_2) - \Delta u(x_1)\bar{d}(x_2)}{u(x_1)\bar{d}(x_2) + \bar{d}(x_1)u(x_2)}$$

$$A_L^{W^-} = \frac{\Delta\bar{u}(x_1)d(x_2) - \Delta d(x_1)\bar{u}(x_2)}{d(x_1)\bar{u}(x_2) + \bar{u}(x_1)d(x_2)}$$

where x_1 is the Bjorken x for the polarized proton and x_2 for the unpolarized proton. The longitudinally polarized up and down quark parton distribution functions are signified by $\Delta u(x)$ and $\Delta d(x)$ while $u(x)$ and $d(x)$ signify the unpolarized distributions. The fact that only the scattered lepton is measured smears the asymmetry by additional factors of $1 \pm \cos(\theta^*)$ where θ^* is the scattering angle of the lepton in the W boson rest frame. While such a smearing reduces the overall magnitude of the asymmetries, it doesn't complicate the unfolding considerably, and the asymmetry is still quite sensitive to the $\Delta\bar{u}$ and $\Delta\bar{d}$ distribution functions.

2 W Bosons at PHENIX

The PHENIX detector consists of two major subsystems capable of measuring W bosons, finely segmented calorimeters at mid-rapidity ($|\eta| < 0.35$) and high resolution muon detectors at forward and backward rapidity ($1.2 < |\eta| < 2.2$). Projected asymmetries in the PHENIX acceptance from [2] can be seen in Figure 1 and suggest very good discriminating power for the W^- boson both at central and backward rapidity and of the W^+ boson at central and forward rapidity.

The PHENIX central arms require no additional upgrades to measure W boson decays to electrons, and first results are likely to be available from the 2009 RHIC run at $\sqrt{s}=500$ GeV wherein PHENIX collected 22 pb^{-1} of data. A fast production of this data has already finished and analysis is currently under way. The central arm detectors consist of high-resolution tracking used to determine the charge and momenta of the outgoing electrons and finely segmented calorimetry for an accurate measure of the energy. Asymmetries from

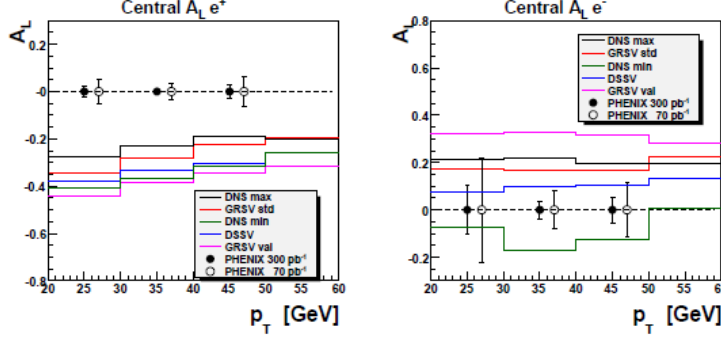


Figure 2: Single Spin Asymmetries for electrons from W^+ (W^-) boson decays on the left (right) in the PHENIX Central Arms. Error bars on open (solid) data points are for 70 pb^{-1} (300 pb^{-1}) of recorded data.

several older parameterizations as a function of transverse momentum can be seen in Figure 2 and give an idea of the size of the expected asymmetries and the expected sensitivity to those asymmetries. This figure, along with Figure 3 were generated with W boson kinematics taken from the RHICBOS event generator[4] and assume 70% Polarization.

Measurements of W boson decays to muons in the PHENIX muon arms are not yet possible, but several upgrades devoted to those measurements are underway. Currently, the limiting factor is the inability of the muon detectors to trigger on single muons effectively enough to fit into the allotted data acquisition bandwidth. Fortunately, muons produced from W boson decays dominate over muon decays from hadrons, which have a very low rate for muon $p_T > 20$ GeV. The upgraded trigger will take advantage of this kinematic difference by using the fine segmentation of the PHENIX muon tracker at the trigger level in order to discriminate between single muons from W bosons and hadronic backgrounds. Timing information from resistive plate chambers (RPCs) will also be used to eliminate beam related backgrounds and give us the ability to determine the crossing in which the collision occurred. Both the upgraded front-end electronics for the muon tracker and the RPCs are currently in production. Expected sensitivity to asymmetries from W boson decays to muons in the PHENIX muon arms are shown in Figure 3.

3 Possible Future Measurements

The rich physics opportunities available from W boson production are not limited to measuring the longitudinally polarized proton structure. Recent theoretical developments have shown that it may be possible to use W bosons as a tool for flavour separation of the quark Sivers function measured from transversely polarized proton collisions [3]. Despite the fact that the asymmetries will be somewhat diluted by the W bosons decay, the predicted asymmetries are substantial and easily measured.

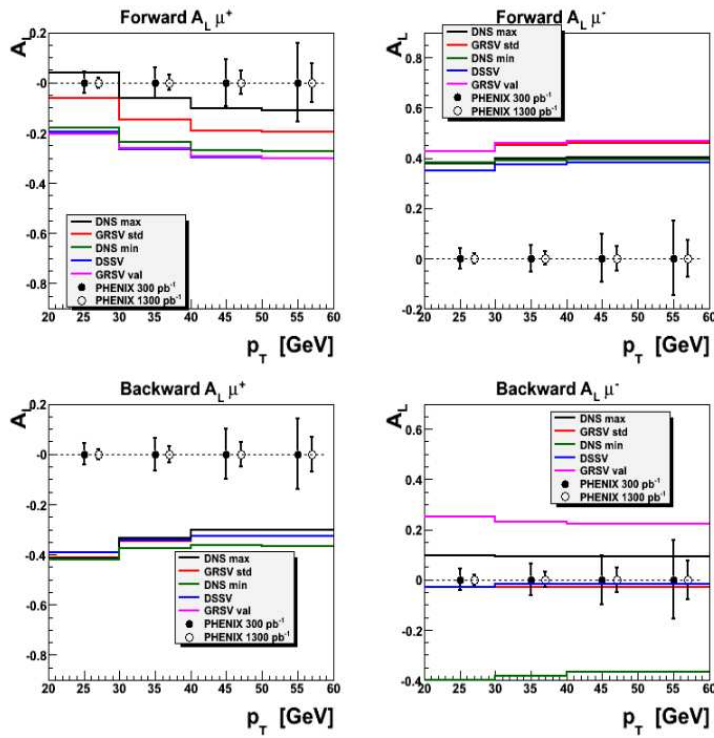


Figure 3: Singe Spin Asymmetries for muons from W^+ (W^-) boson decays on the left (right) in the PHENIX Muon Arm including 3/1 signal-to-background and is plotted against reconstructed p_T . Error bars on solid (open) data points are for 300 pb^{-1} (1300 pb^{-1}) of recorded data. ‘Forward’ and ‘Backward’ refer to the direction of the muon relative to the momentum of incoming the polarized proton.

4 Conclusions

Operation of RHIC at $\sqrt{s}=500\text{GeV}$ provides an exciting opportunity for PHENIX to contribute to the understanding from SIDIS measurements of the longitudinally polarized anti-quark parton distribution functions and possibly to future transversely polarized measurements as well. The PHENIX detector is well prepared to make measurements of W boson decays to electrons at mid-rapidity and will soon be prepared to make measurements of decays to muons at forward and backward rapidity. This large kinematic coverage places the PHENIX experiment in a position to fully explore the physics provided by W boson production in polarized proton collisions.

References

- [1] Slides:
<http://indico.cern.ch/materialDisplay.py?contribId=318&sessionId=4&materialId=slides&confId=53294>
- [2] D. de Florian *et al.*, arXiv:0904.3821 (2008).
- [3] Z. Kang and J.W. Qiu, arXiv:0903.3629 (2009).
- [4] P.M. Nodolsky and C.P. Yuan, arXiv:hep-ph/0304002 (2003).